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INSTALLATION OF A HIGH GAIN LONG PERIOD SEISMOGRAPH STATION

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Two high gain (100K) long period (T_0=30 sec) horizontal seismic systems have been added to the White Pine Seismological Observatory which have proved to be extremely stable, more so in fact than the vertical, for long term recording. The high gain vertical seismic system was switched from photo-tube amplifier to solid state Geotech AS-650 amplified. With included FM telemetry capability this permitted recording of the HGLP vertical velocity signal at the surface. The vertical velocity output amplified with the Geotech 5240-A phototube amplified was compared with simultaneously recorded vertical velocity output

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) amplified with the Geotech AS-650 solid state amplifier. This study revealed the phototube amplifiers to be substantial noise generating mechanisms in the period range 10-200 seconds. In addition, phototube amplifier filtration systems often obscure body wave phase arrivals which the AS-650 did not. For routine seismogram interpretation, the output of the AS-650 was a substantial improvement over the 5240-A output. A surface recording facility has been established in the northeast corner of the Bechtel Building of the White Pine Copper Company. Space has been allocated for the Astrodata data logger system, four helicorder type recorders with associated electronics, two strip chart recorders, a discriminator demultiplexer system and WWV radio assembly. Equipment currently operating consists of a short period (1 Hz) and long period (0.033 Hz) vertical recording system. Two gain levels of long period velocity information are being recorded, 10K and 100K. We are awaiting the arrival of two helicorders with associated electronics, two XD-410 discriminator systems and a WWV receiver which are scheduled to arrive early December, 1974. The algorithm for epicenter location using surface waves is nearing completion. Preliminary tests using theoretical data have yielded satisfactory results. Testing of the algorithm using real data is scheduled to begin the first of October. The algorithm will be given to the National Earthquake Information Services in the latter part of October. This development has been desirable to study events for which locations by conventional methods are not always available.

TABLE OF CONTENTS

*Whenever HGLP East-West records are included, they are advancing at 15 mm per minute instead of 12.5. The seismograms were recorded in a strip chart recorder loaned by the White Pine Copper Company.

Technical Report Summary
Contract No. F44620-73-C-0060

Two high gain (100K) long period (T_O=30 sec) horizontal seismic systems have been added to the White Pine Seismological Observatory. They have been installed in a subsurface vault adjacent to, but separate from the vertical instrumental vault completed in 1973. They have proved to be extremely stable, more so in fact than the vertical, for long term recording. A modification of the isolation tanks (i.e., removal of the tank bottom) prior to installation has effectively decoupled the seismometers from the tanks. It is this decoupling which may account for the stability of the horizontal seismometers.

The high gain vertical seismic system was switched from phototube amplifier to solid state Geotech AS-650 amplifier. With included FM telemetry capability, this permitted recording of the HGLP vertical velocity signal at the surface. Successful recording at a gain of 100K was possible when galvanometric band rejection signal conditioning was included to reduce six second microseismic noise.

The vertical velocity output amplified with the Geotech 5240-A phototube amplifier was compared with simultaneously recorded vertical velocity output amplified with the Geotech AS-650 solid state amplifier. This study revealed the phototube amplifiers to be substantial noise generating mechanisms in the period range 10-200 seconds. In addition, phototube amplifier filtration systems often obscure body wave phase arrivals which the AS-650 did not. For routine seismogram interpretation, the output of the AS-650 was a substantial improvement over the 5240-A output.

A surface recording facility has been established in the northeast corner of the Bechtel Building of the White Pine Copper Company. Space has been allocated for the Astrodata data logger system, four helicorder type recorders with associated electronics, two strip chart recorders, a discriminator demultiplexer system and WWV radio assembly. Equipment currently operating consists of a short period (1 H_z) and long period (0.033 H_z) vertical recording system. Short period records are on helicorder, long period records are on six-inch strip charts. Two gain levels of long period velocity information are being recorded, 10K and 100K. We are awaiting the arrival of two helicorders with associated electronics, two XD-410 discriminator systems and a WWV receiver which are scheduled to arrive early December, 1974.

The algorithm for epicenter location using surface waves is nearing completion. Preliminary tests using theoretical data have yielded satisfactory results. Testing of the algorithm using real data is scheduled to begin the first of October. The algorithm will be given to the National Earthquake Information Services in the latter part of October. This development has been desirable to study events for which locations by conventional methods are not always available.

I. Station Construction and Installation

a) Horizontal seismometer tank installation - Construction of a subsurface seismic vault to test a vertical HGLP instrument was completed in June, 1973 (see Technical Report 1 April-30 September 1973, ARPA Order No. 1827) in section 31-A of the White Pine Copper Mine, White Pine, Michigan. This vault (Figure 1, vault 1) subsequently was found to have insufficient suitable floor space to install horizontal instruments. In May, 1974, construction of an adjacent vault was begun (Figure 1, vault 2) to house the HGLP horizontal tanks. All loose floor debris was removed before wall construction was begun. This substantially reduced the difficulty of selecting tank installation sites since the entire vault 2 floor was exposed. Although production blasting had reduced the usable floor space, as in vault 1, two unfractured, unjointed sections of the Copper Harbor Conglomerate (see geologic column, Figure 3) were deemed suitable for tank placement. These sections of floor were meticulously cleaned and any loose fragments removed. This resulted in relatively smooth, impermeable tank foundations.

Unlike other HGLP installations, where prestressing of the tank bottom was necessary to insure proper bonding of the metal to concrete beneath it, we chose to minimize tank tilt effects on the horizontal seismometers by decoupling the two components. Before installation, the tank bottoms were cut out leaving only a rim four inches wide for bonding. Four cadmium plated threaded rods for each tank were then cemented 38 centimeters into bedrock using an epoxy resin. The use of epoxy bolts rather than mechanical bolts was suggested by mine personnel. Both resin and mechanical bolting are widely employed in the White Pine Mine, and resin bolting has been shown to be more effective than mechanical bolting. Since it was unnecessary to insure a bottom contact with concrete, prestressing of the tank was unnecessary. The tank was then set onto a slurry of sand and cement and bolted securely to the bedrock. By wobbling the tank before final bolting, it was possible to reduce the average thickness of the cement to less than 5 millimeters. The cement was then permitted to cure for three days undisturbed. Following the curing period, the inside of the tanks, bedrock and concrete junctions were triple-sealed with epoxy. The concrete outside the tank was also sealed. Each epoxy coat was permitted to harden thoroughly before the next was applied. Finally, the interior and exterior of each tank was coated with zinc chromate to inhibit rust formation.

All but two ports entering the tanks were sealed with teflon-coated plugs which were tightened and then coated internally and externally with General Electric Glyptal 1201. The remaining two ports were fitted with Marsh-Marine connectors which clamped onto molded wire plugs.

b) Cabling of horizontal seismometers - Data and control cables were run from the control area in vault 1 (see Figure 1) to the seismometer tanks in vault 2. To minimize pressure leakage into the seismometer tanks, all cables entering the tanks were stripped of insulation, sealed with General Electric Glyptal 1201, and potted in 3M Scotchcast resin plugs. The resin plugs were then seated in the Marsh-Marine connectors to insure pressure integrity of the sealed system. Several different castings of the plugs were necessary before useable plugs could be obtained. It was found that the 3M Scotchcast resin became brittle and shattered upon removal from the molds if permitted to harden in the ambient mine conditions. Good plugs could be obtained only when the molds were continuously warmed with heat lamps during the hardening process. Control cabling consisted of Belden 6-pair shielded instrument cable. All other wiring was done with individual shielded pair cable to reduce cross-talk between pairs and maintain integrity of the data lines.

c) Subsurface instrumentation - A description of the HGLP vertical system has been given (see Technical Reports 1 April - 30 September 1973, and 1 October 1973 - 31 March 1974; ARPA Order No. 1827). The results of experiments using the phototube amplifier and Geotech AS-650 amplifier are discussed in Section II of this report. Additional equipment installed in the vaults during this report period consists of two HGLP horizontal seismometers, three phototube amplifiers, and a new subsurface control rack.

The horizontal seismometers employed at station WPM are Geotech model 8700C's which have been modified to accommodate Sprengnether model VCT-210 displacement transducers. The natural frequency of each instrument has been set at 0.033 Hertz (T_o=30 sec). Following calibration, each seismometer with its associated displacement transducer electronics was thoroughly insulated with spun glass and then sealed in its tank. With no physical connection between the tank and seismometer, C-clamps could be tightened until the seismometers "quieted down". There was a direct connection between the output noise and effectiveness of the tank seal, and the noise level would dramatically decrease when a good seal was effected. Since there was no direct connection between tank and seismometer, stresses induced in the tanks during clamping were not transmitted as tilts to the seismometers. Hence, it was possible to tighten or loosen clamps or add additional clamps, as necessary, without affecting the seismometers. Throughout the clamping procedure neither seismometer needed recentering. Further discussion of instrumental stability is in Section II of this report.

In addition to the seismometers, a subsurface control area has been installed in the northeast corner of vault 1. Three phototube amplifiers have been made operational as well as a Geotech AS-650 solid state amplifier (see Photographs 2 and 3). Recording of horizontal seismograms was done on two Esterline Angus model S601-S six-inch strip chart recorders in the subsurface control area throughout the summer of 1974. Instrumentation in the subsurface control rack consists of a boom position monitor and reposition motor drive panel, a calibration panel, a waveform generator, a Sprengnether S-100 chronometer, and power regulation and distribution devices. All boom monitoring and repositioning for both vertical and horizontal seismometers, as well as calibration, must be effected from this rack. No calibration or repositioning capability exists, or is likely to exist, at the surface recording site. The telemetry link to the surface recording site for frequency modulated signals is also accessible at a panel in the subsurface control area.

Figure 3 schematically illustrates, in block diagram, what the present and future configuration of the subsurface facility will be. Although, the phototube amplifiers and AS-650 amplifier will be replaced with Ithaco low-noise solid state amplifiers, FM multiplexing of signals will be necessary to transmit them to the surface for recording. The center frequencies of the VCO's used are given within each appropriate block.

d) Surface instrumentation - A surface recording facility has been established in the northeast corner of the Bechtel Building of the White Pine Copper Company (see Photographs 4 and 5). When the station is completed, all recording will be done in this room. At the end of this report period, the following instrumentation has been installed: three Geotech XD-410 discriminator units to demultiplex and separate subsurface data signals: one, presently non-working Astrodata data logger system (the timing mechanism for this unit supplies all time marks for the surface recorders); two Esterline Angus S601-S strip chart recorders, which currently record a high gain and low gain vertical long period signal; a helicorder and amplifier which record the short period vertical signals.

Figure 4 illustrates, in block diagram, what the completed system for the surface will be. Unlike other HGLP stations, WPM will not be able to record photographically. Therefore, we have chosen to do recording on helicorders to more closely match the other station formats. The center frequencies of the discriminators are given within each appropriate block.

II. Accomplished Research to 1 October 1974

a) Comparison of Geotech AS-650 solid state amplifier and phototube amplifier - In June, 1974, the long period vertical instrument was switched from phototube amplifier to a Geotech AS-650 solid state amplifier. This permitted recording of long period vertical, in addition to short period vertical, seismic signals on the surface since the output of the AS-650 was multiplexed to a 1020 Hertz carrier. The successful recording of the short period vertical signal on the surface has been discussed previously (see Technical Report 1 October 1973 - 31 March 1974; ARPA Order No. 1827). No interference or direct coupling between the long period and short period systems was observable on nearly continuous records from June to September 1974. Further discussion of the short period system is given in part b) of this section.

The Geotech AS-650 amplifier, unlike the phototube amplifier, does not have a 0.167 Hertz notch filter incorporated. This resulted in high six-second microseismic noise, especially during "storm" periods. This noise proved to be the principal gain limiting factor for the WPM long period vertical system. The vertical magnification ranged from 88K during periods of intense microseismic activity to 100K during quiet "noise" periods. The bottom trace of Figure 6 illustrates the signal appearance during an intense noise period. To reduce this effect, a galvanometric preconditioning scheme was employed (see Pomeroy et. al.; B.S.S.A., Vol. 50, pp 135-151, 1960). A Leeds and Northrop critically damped 0.167 Hertz galvanometer was inserted in series between the seismometer and AS-650 amplifier (Pomeroy P2F configuration). The galvanometer in this mode acted as a band rejection filter, preconditioning the signal before amplification. This resulted in a six-second microseismic noise reduction by a factor of two (upper trace, Figure 6). The use of the galvanometric band rejection filter scheme, therefore, is being employed with the AS-650 amplifier at WPM on HGLP vertical signals. Two gain levels, 10K and 100K, are being recorded for the HGLP vertical.

During the period 1 through 4 August 1974, a comparative test was run using the vertical seismometer. The signal from one data coil was amplified using the Geotech AS-650 solid state amplifier. Simultaneously, the signal from the other data coil was amplified using the Geotech 5240-A phototube amplifier. The AS-650 employed the galvanometric band rejection filtering technique previously described while the phototube amplifier employed the Geotech 6824-15 special filter. Three of the seismograms recorded in this manner are included in this report (see Figures 7-9). This comparison revealed several important facts: (1) most of the longer period (20 to 100 seconds) noise was being generated within the phototube system since it did not appear on the AS-650 records; (2) although gain levels appear to be higher for periods in the 50 to 60-second range from the phototube amplifiers, substantial distortion of 10 to 20-second periods exists; (3) usually body phase arrivals are substantially more recognizable on the AS-650 records. We believe, therefore, that the seismograms from the AS-650 are more useful to seismologists than those from the Geotech 5240-A phototube amplifiers. Hopefully, the Ithaco replacements will exhibit more of the characteristics of the AS-650 than the 5240-A.

b) Suitability of the White Pine Mine for a complete HGLP installation - The White Pine Copper Company experienced a strike shutdown during the latter two weeks of August. During this period, only routine maintenance of underground and surface facilities was undertaken by limited mine personnel. This was, therefore, an ideal time to see what affect the mining operations had on the seismic signals at WPM. There was no noticeable affect on any of the three HGLP instruments; that is, there appeared to be no reduction of long period noise. The short period vertical system underwent substantial signal enhancement. During active mining periods, the short period vertical is operable at a maximum gain of 25K. The gain limiting factor is a persistent 4 Hertz resonance associated with mining activities and possibly surface milling operations. The response curve for the short period system is given in Figure 5a, curve a. During the shutdown period, the gain could be raised by at least a factor of 4 and possibly greater. It is, therefore, apparent that to run a high gain vertical short period instrument (gains of 100K or more, curve b, Figure 5a), it must be remote from the active mining area of the White Pine Copper Company. Prior to the installation of the HGLP vertical instrument in 1973, a micro-earthquake survey was run. Gains in excess of 100K could be obtained at a distance of 10 miles from the White Pine mining operations.

The environmental stability of the WPM seismic vaults has been discussed in previous technical reports (see TR 1 April - 30 September 1973; TR 1 October 1973 - 31 March 1974; APRA Order No. 1827). At that time the long period vertical instrument had been successfully operated at gains in excess of 400K. The horizontal instruments, installed during June and July, 1974, also have proved to be very stable. The horizontal instruments, in fact, have been far more stable than the vertical. They require less frequent recentering than the vertical and have gone for periods of a week or more, immediately following installation, during which there was no apparent drift at all. Presumably this stability is a reflection of the decoupling of the seismometer from its pressure tank. The stability of the horizontals is disrupted, however, when personnel enter vault 2 (possibly a thermal agitation affect or actual vault tilt), and so entrance is restricted to major maintenance only. Figure 5b illustrates the response curves of the three WPM HGLP instruments. Five selected events recorded at WPM are illustrated in Figures 10-14.

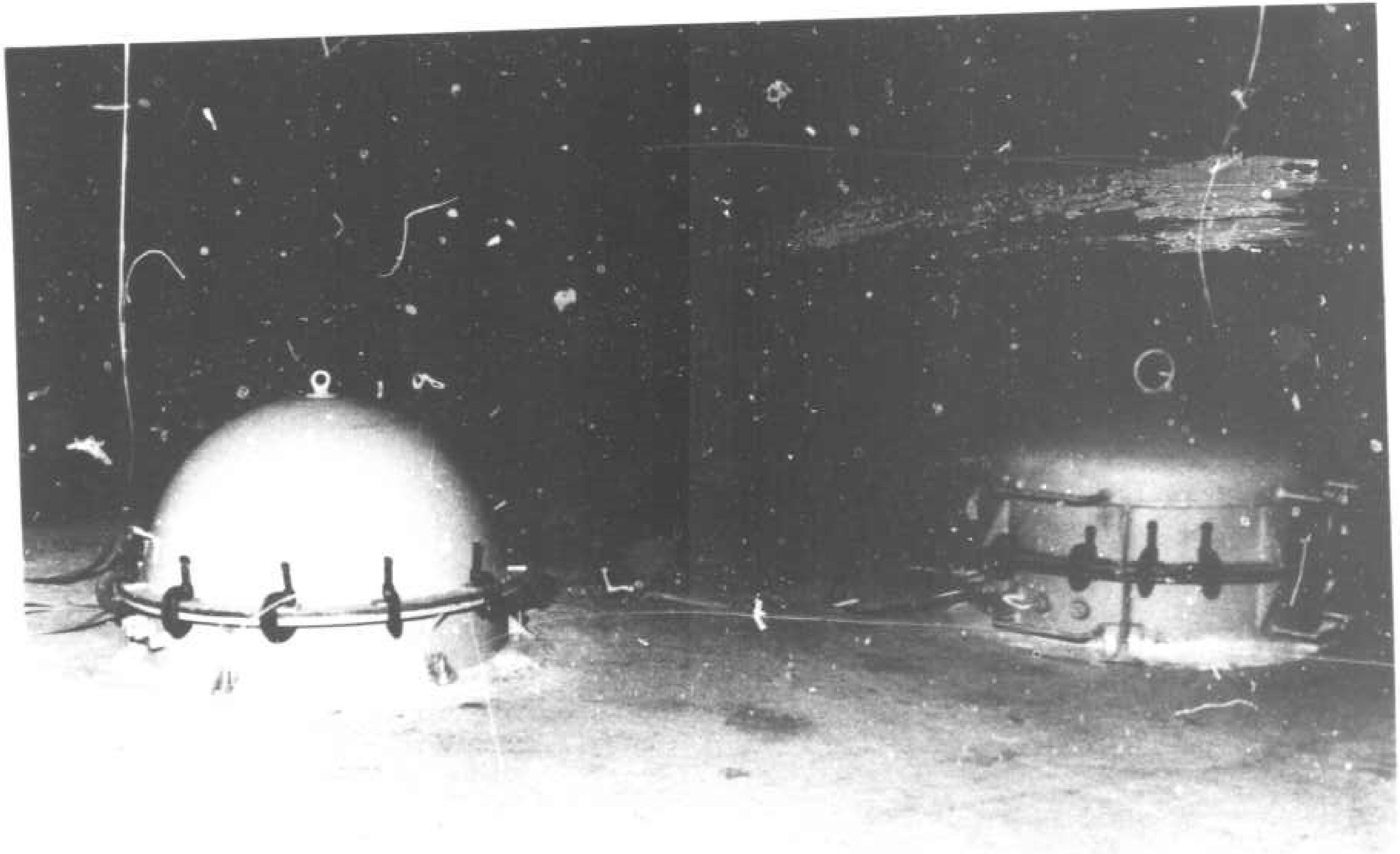
Difficulties with the installation during this report period are as follows:

(1) Stability of the power supplied by the White Pine Copper Company both on the surface and underground has become suspect. During this report period, the underground installation has experienced no less than four major power outages, the surface installation more than ten. Damage of the AS-650 amplifier occurred due to surging when power was resumed. To prevent recurrence of this, an adequate power isolation system is required both above and underground.

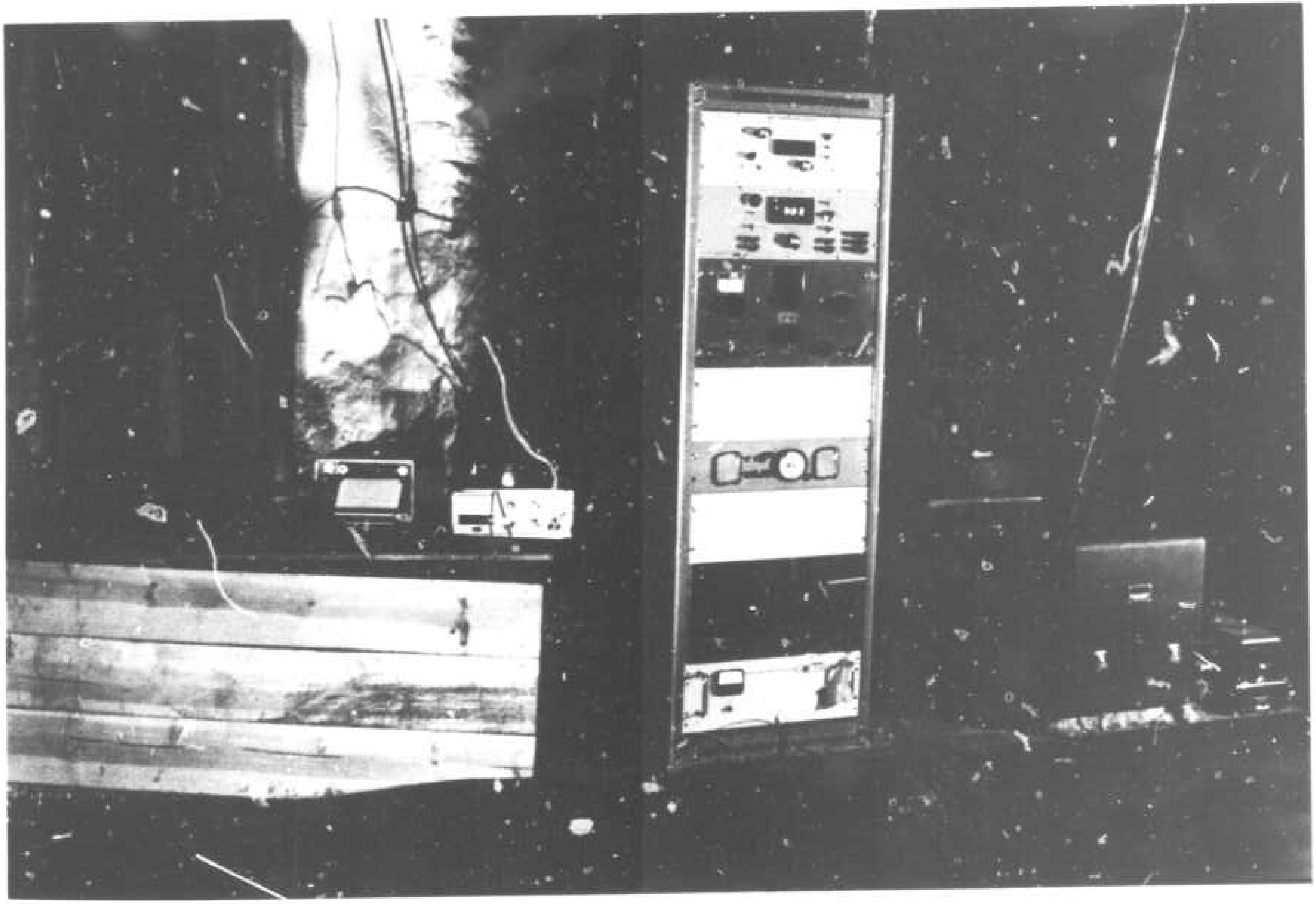
(2) Recording of horizontal seismograms was accomplished in vault 1 of the underground facility. To complete the installation, these signals must be telemetered to the surface. This includes displacement transducer signals as well as velocity transducer signals.

(3) Many problems exist with the Astrodata data logger system, which must be corrected with the assistance of Albuquerque Seismological Center personnel.

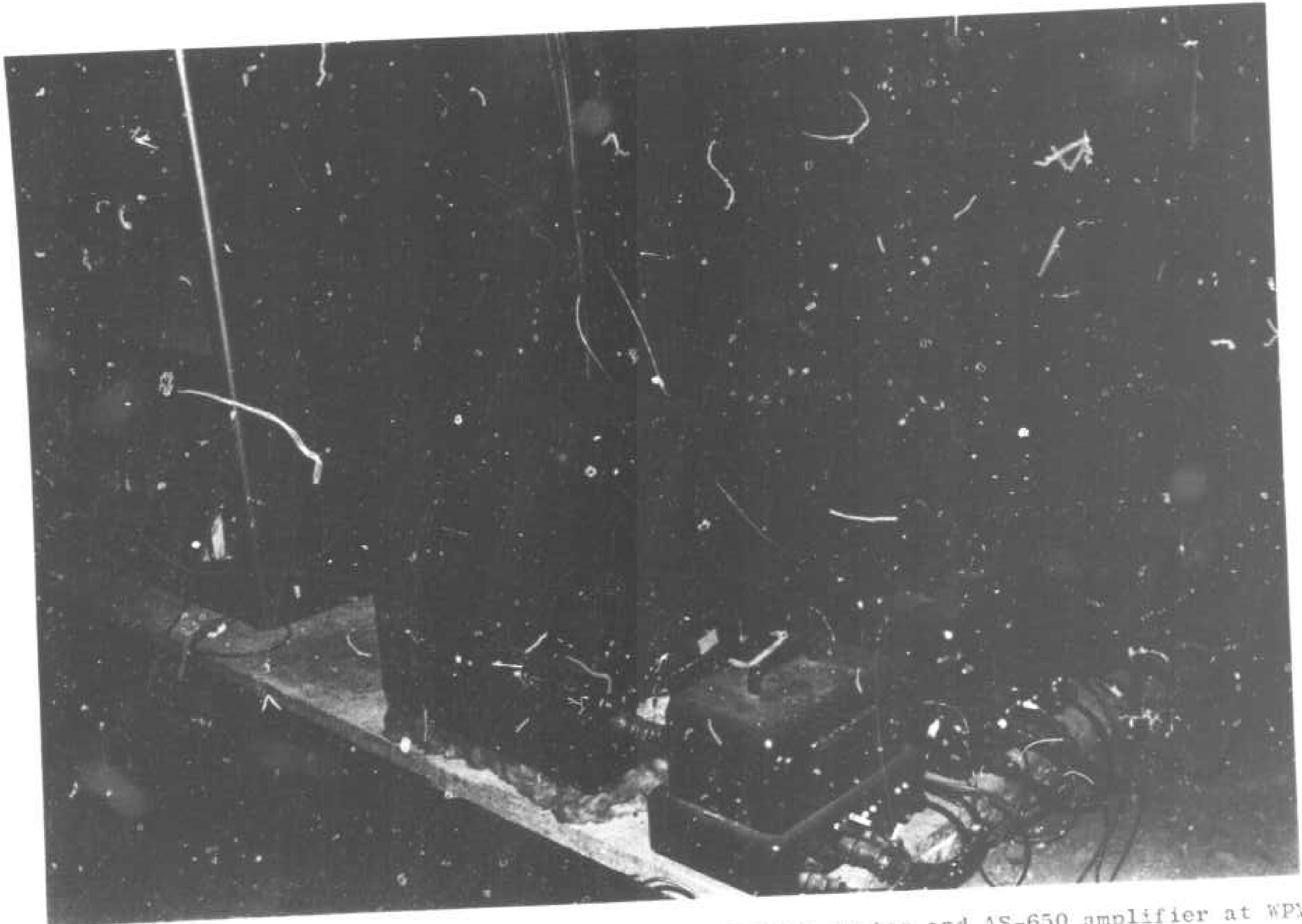
c) Completion of the Algorithm for epicenter location using surface waves - The algorithm EPI-HGLP is based on Geiger's method for the determination of an epicenter location and time of origin based on arrival time data of several stations. Additional modifications suggested by Bolt (Nature, Vol. 217, 1968, p.47) are included. It employs a least squares error method to arrive at a best fitting epicentral latitude, longitude, and origin time using Raleigh wave arrival time data. Theoretical testing of the algorithm has been completed with satisfactory results. Testing of realistic data using WWSSN seismograms has begun. The University of Michigan Seismological Observatory surface wave epicenter location algorithm is scheduled for completion by the latter part of October when it will be turned over to the National Earthquake Information Services. This development has been desirable in order to study events for which locations by conventional methods are not always available.



Photograph No. 1 - HGLP horizontal seismometer pressure tanks at WPM

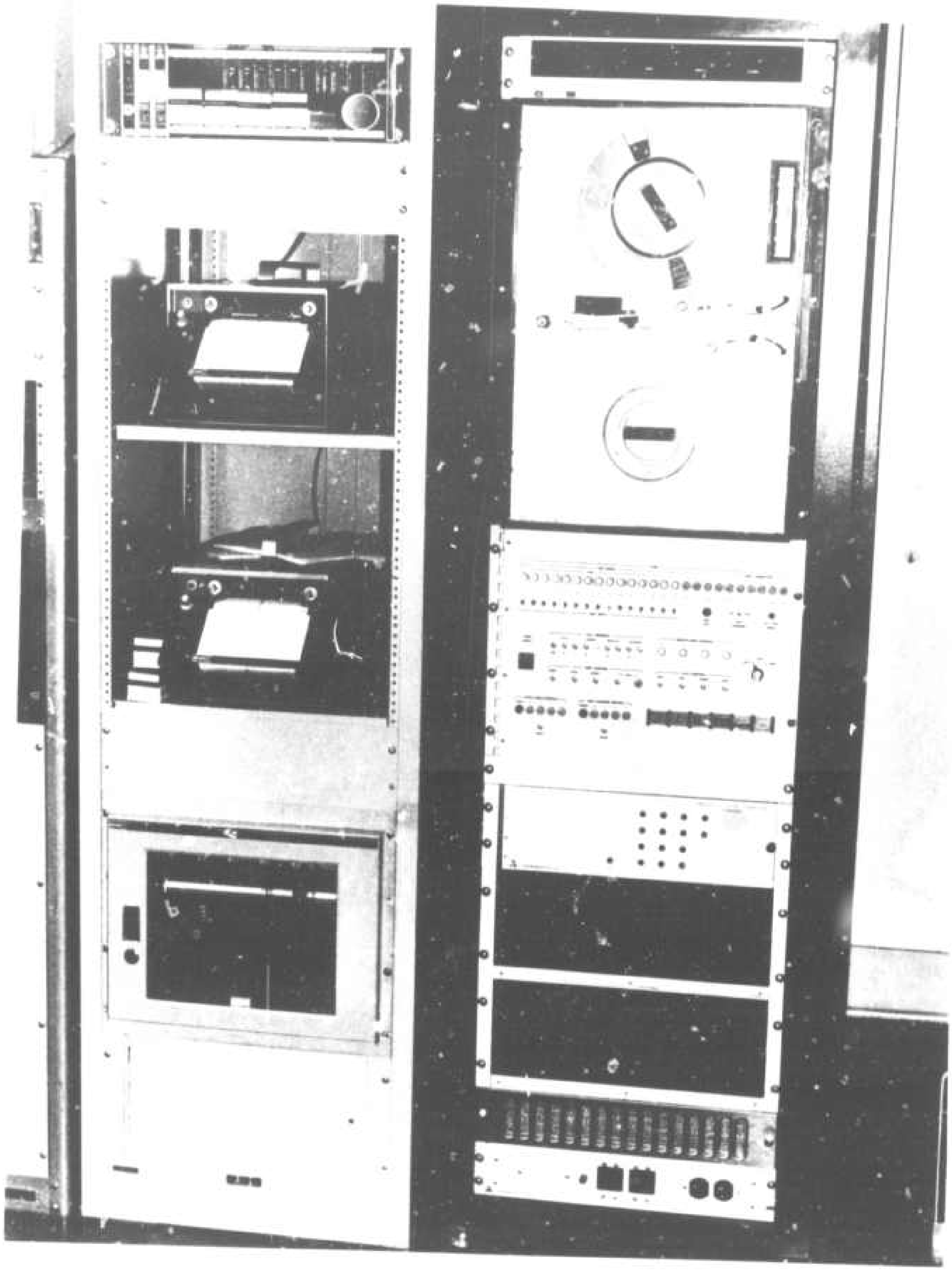


Photograph No. 2 - Subsurface control area for calibration and boom recentering



Photograph No. 3 - Three component phototube amplifier system and AS-650 amplifier at WPM

Photograph No. 4 - Half of the surface recording facility displaying long and short period vertical recorders



Photograph No. 5 - Half of the surface recording facility displaying the Astrodata data logger system

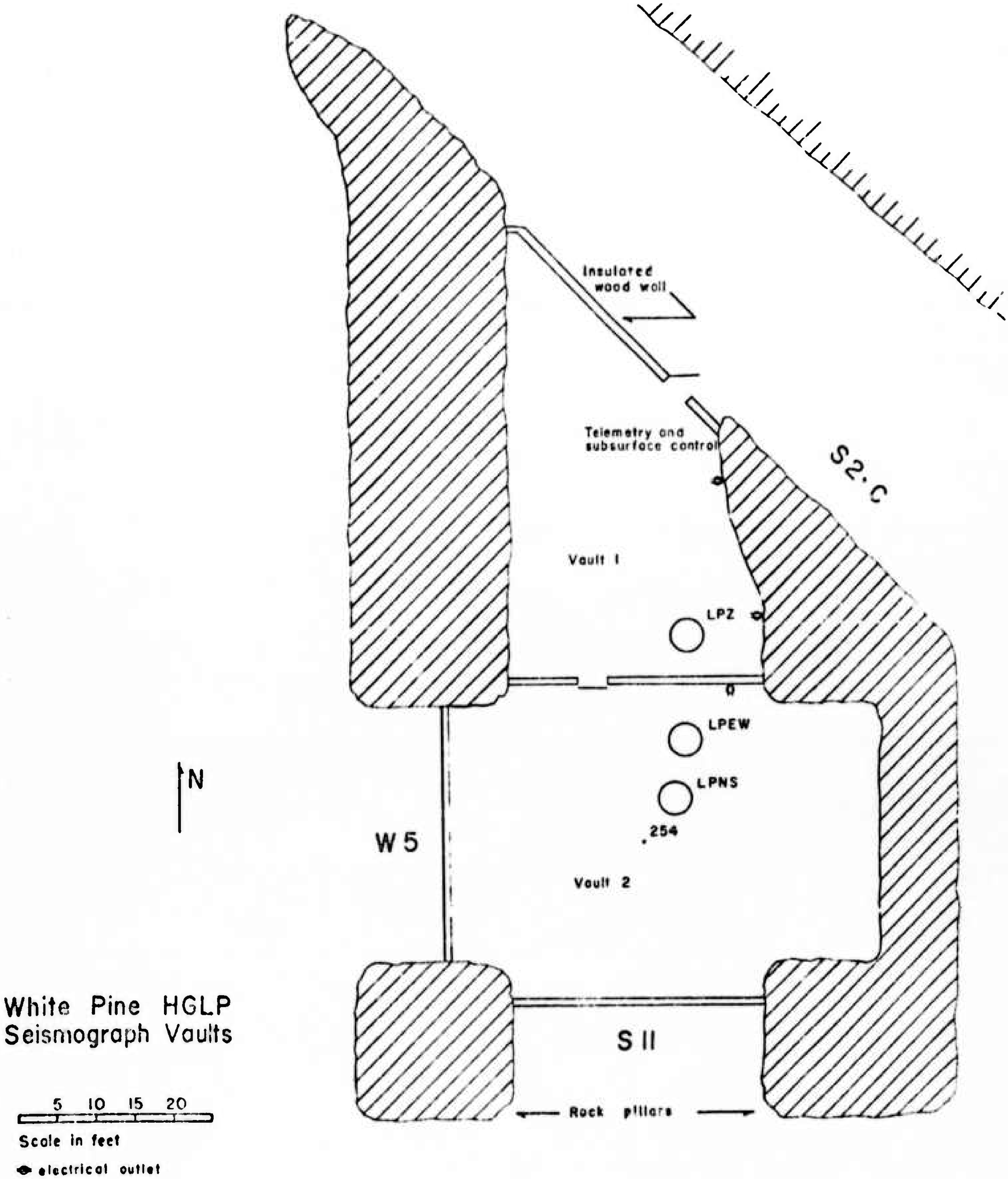


Figure 1 - Subsurface vault schematic diagram for station WPM illustrating instrument Placement

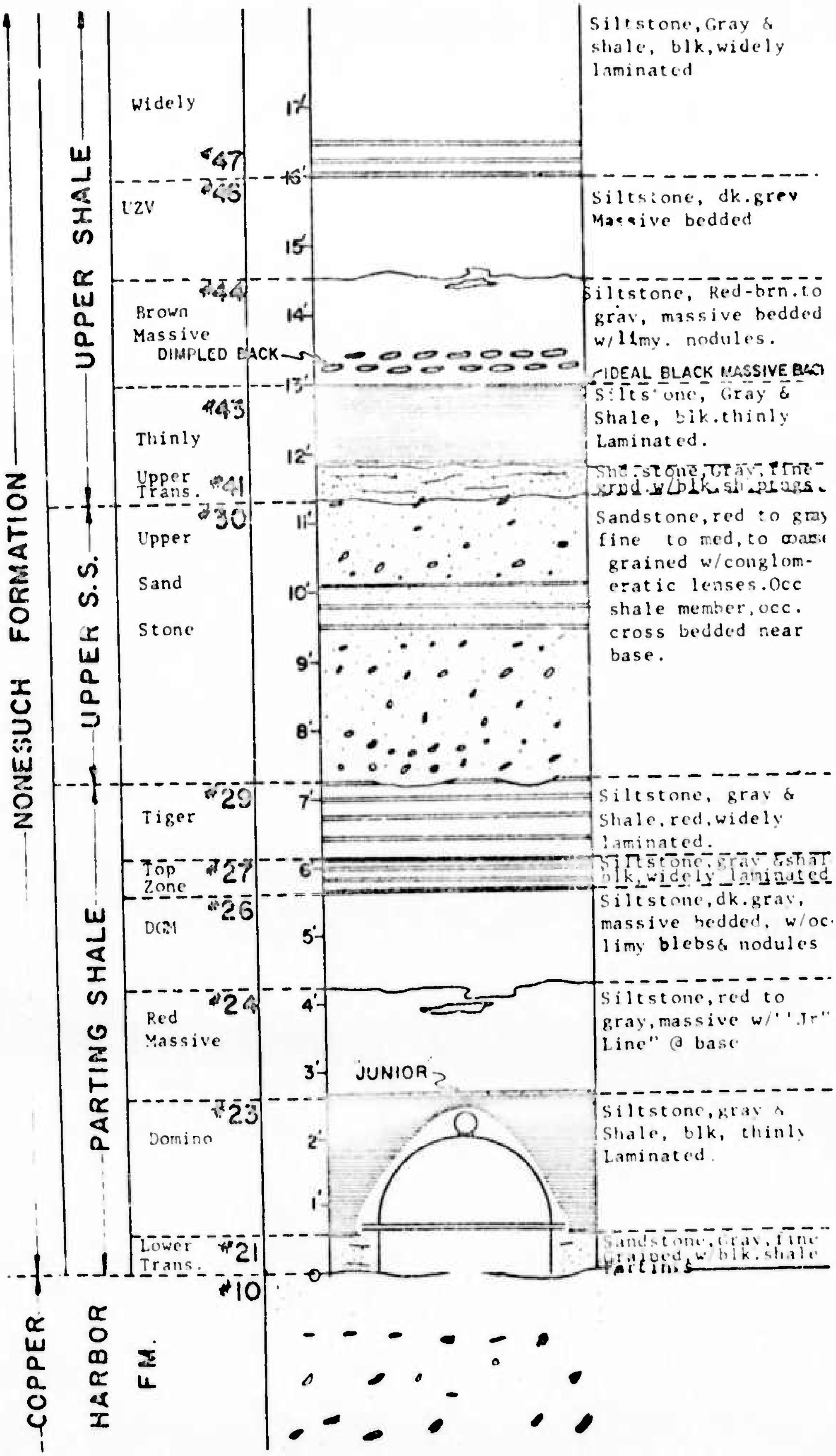


Figure 2 - GEOLOGIC COLUMN FOR SEISMIC STATION WPM

Figure 3-HGLP STATION WPM SUBSURFACE SCHEMATIC DIAGRAM

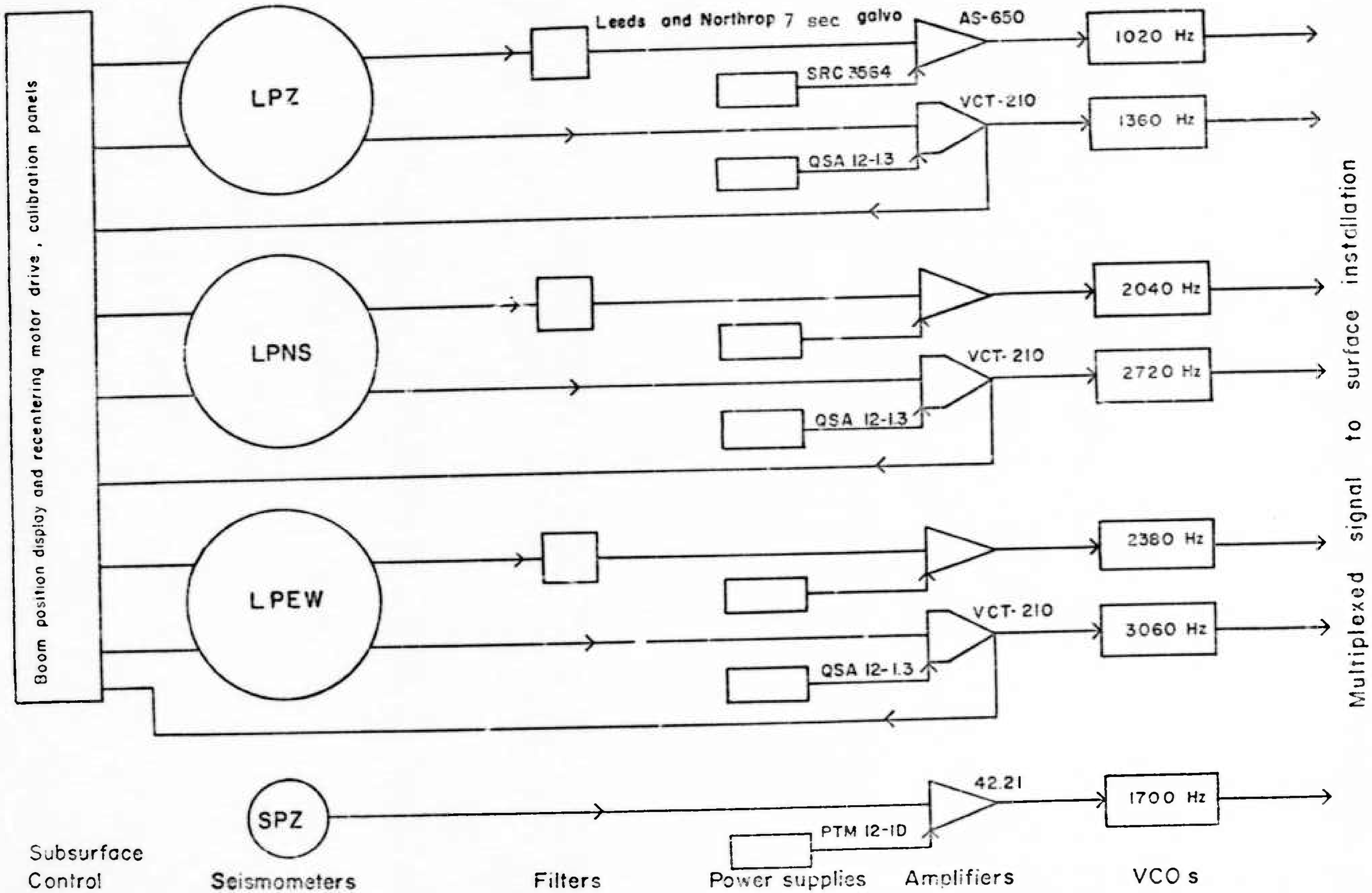


Figure 4

HGLP STATION WPM SURFACE SCHEMATIC DIAGRAM

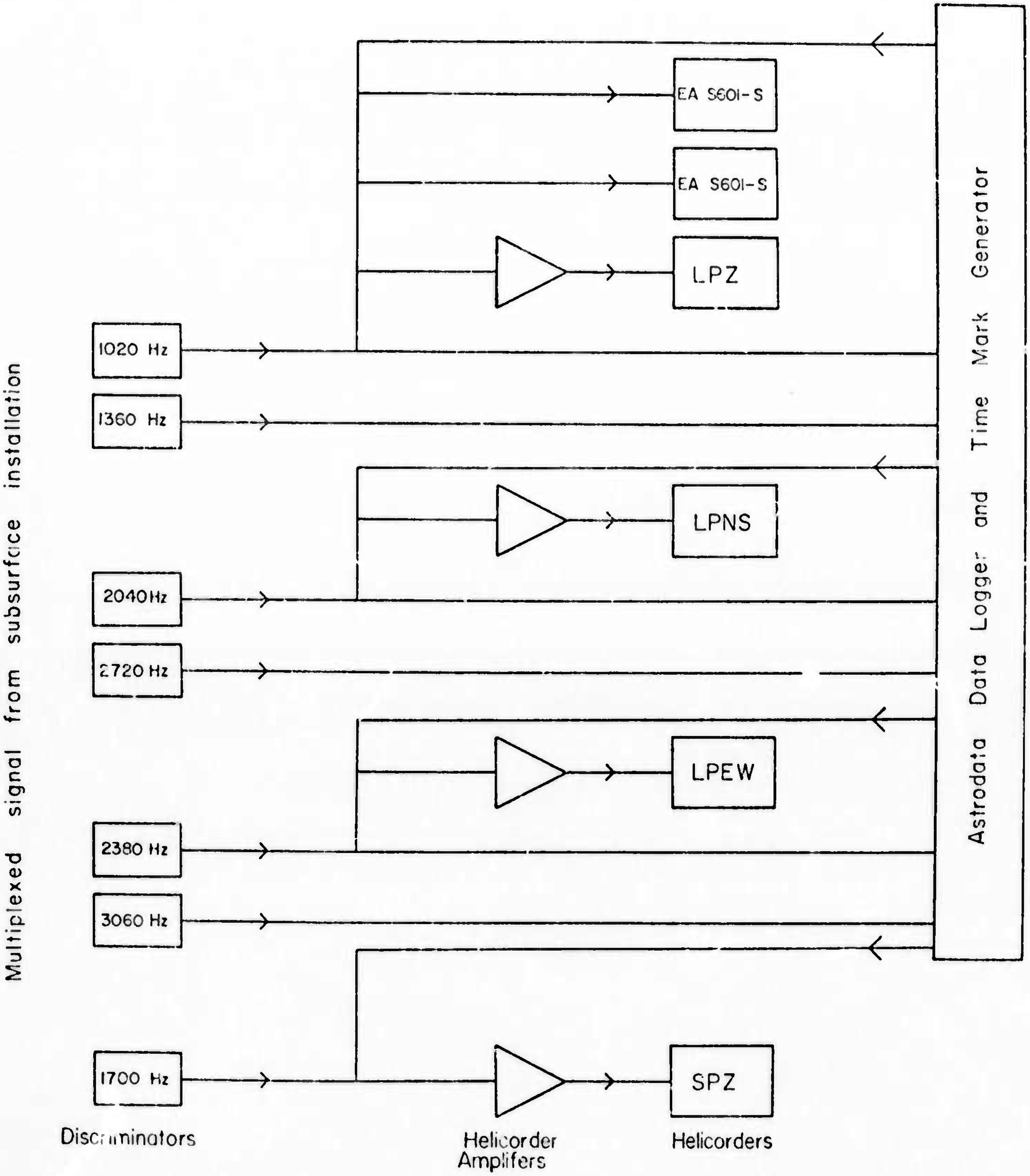


Figure 5a
Short period vertical
instrumental response curve

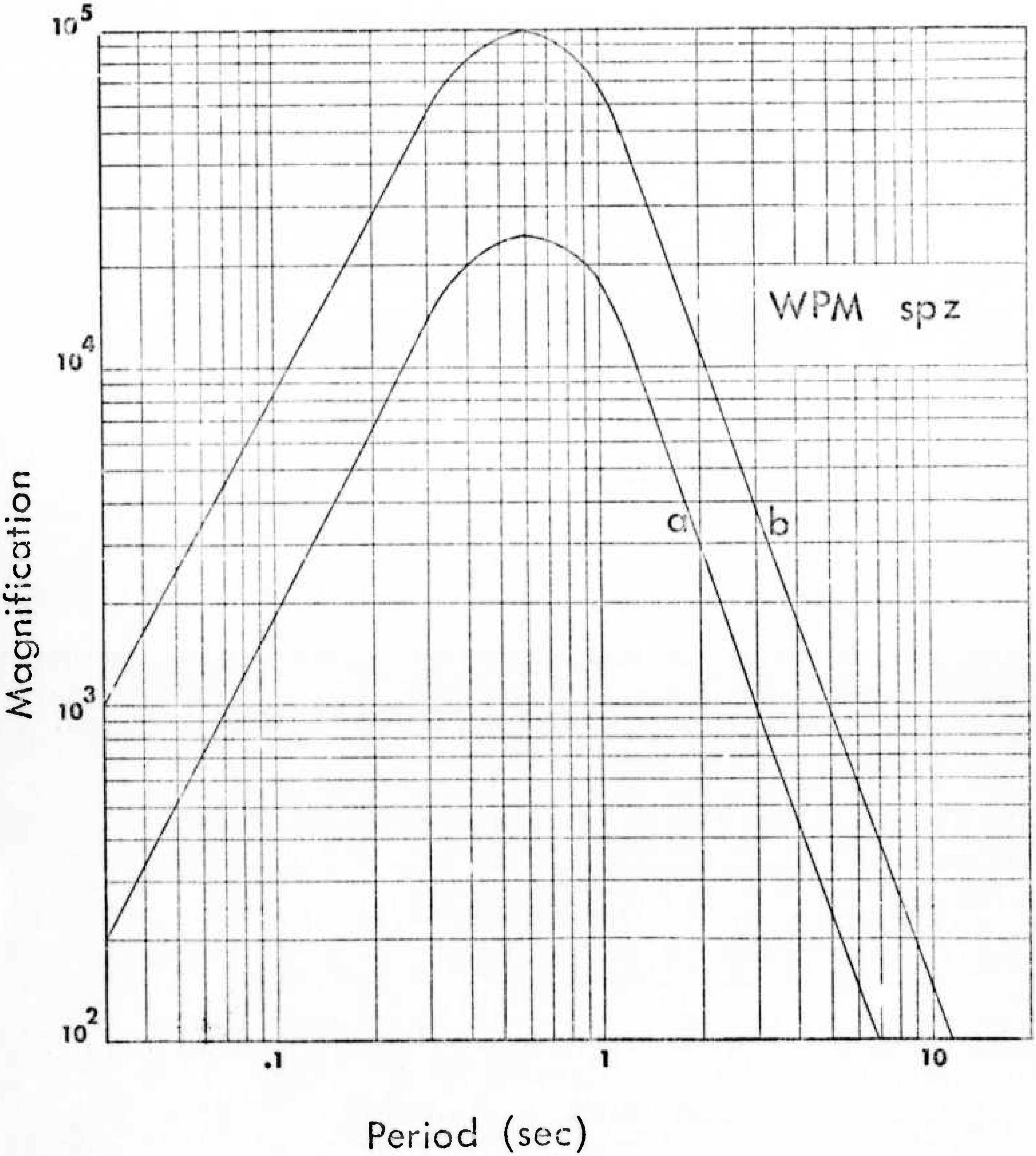


Figure 5b
Long period instrumental
response curves for WPM

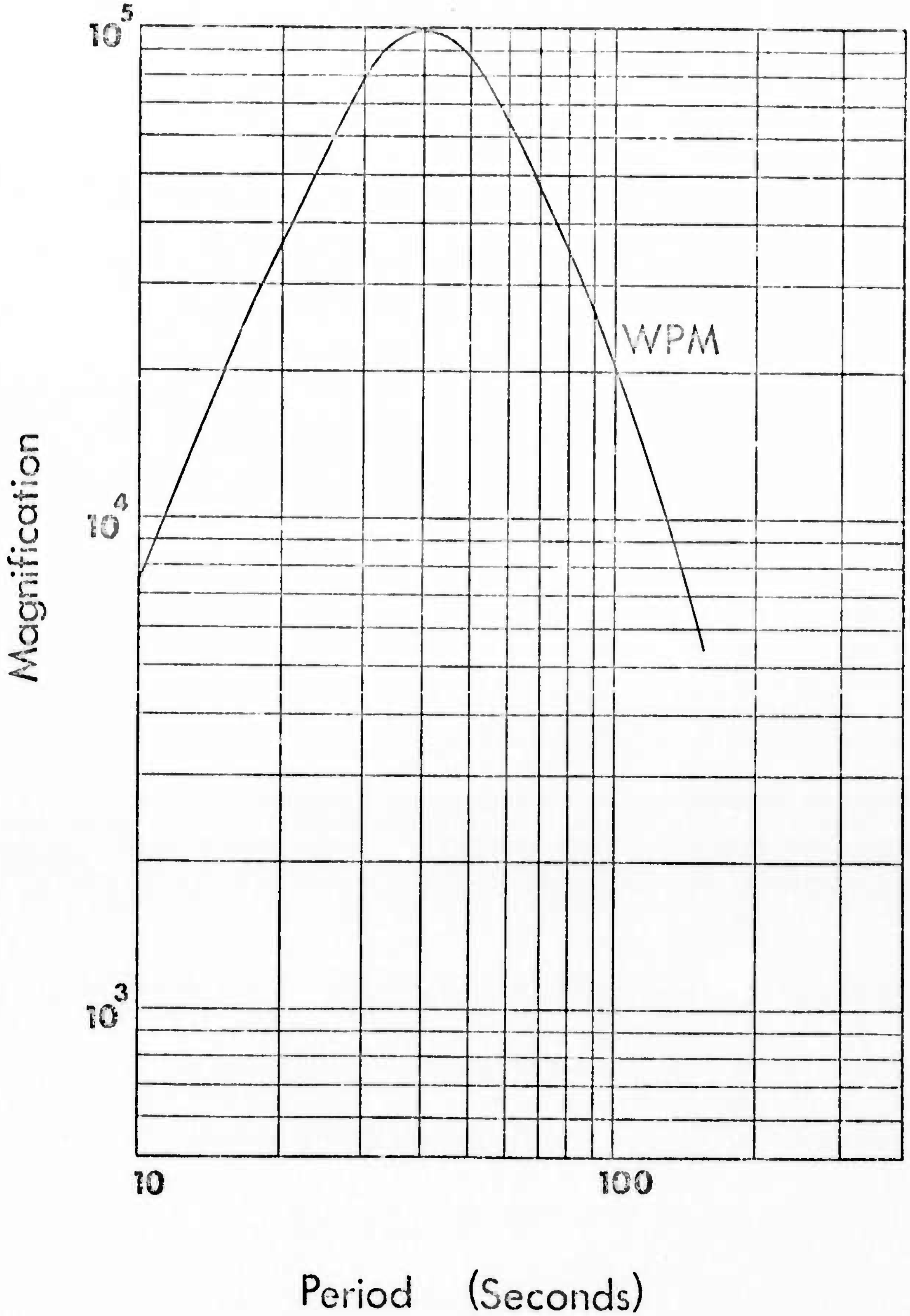
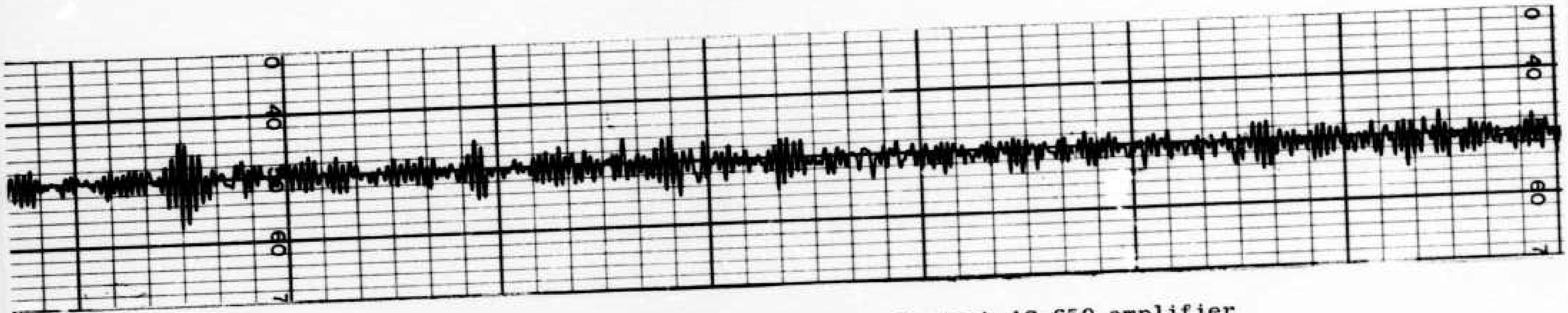
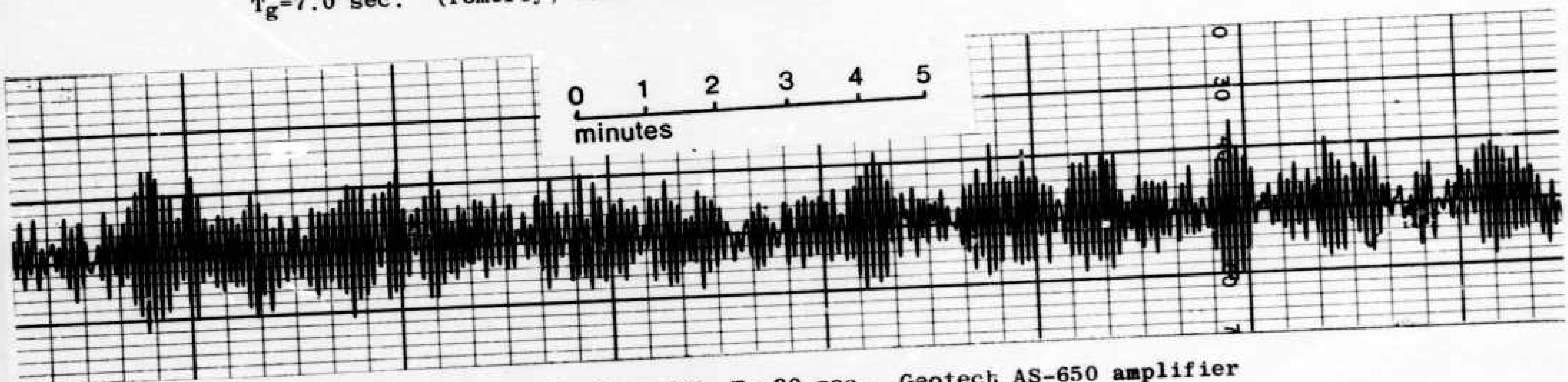


Figure 6

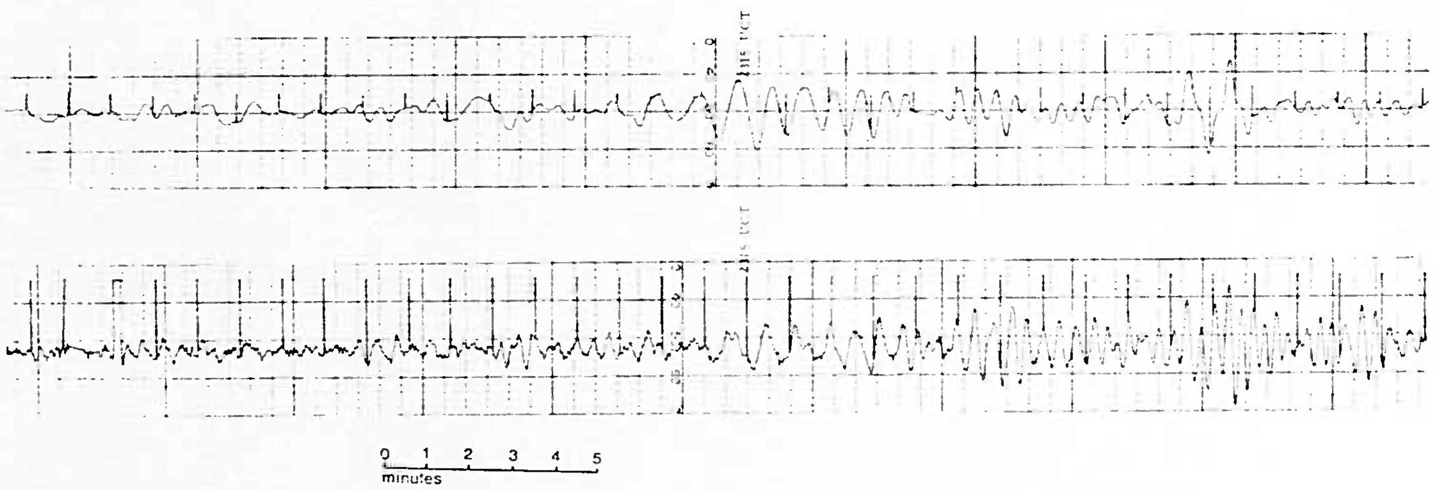


Vertical seismogram Station WPM T_o=30 sec. Geotech AS-650 amplifier
Gain 88,000 employing Leeds & Northrup bandpass filter galvanometer
T_g=7.0 sec. (Pomeroy, 1960: P2F configuration)



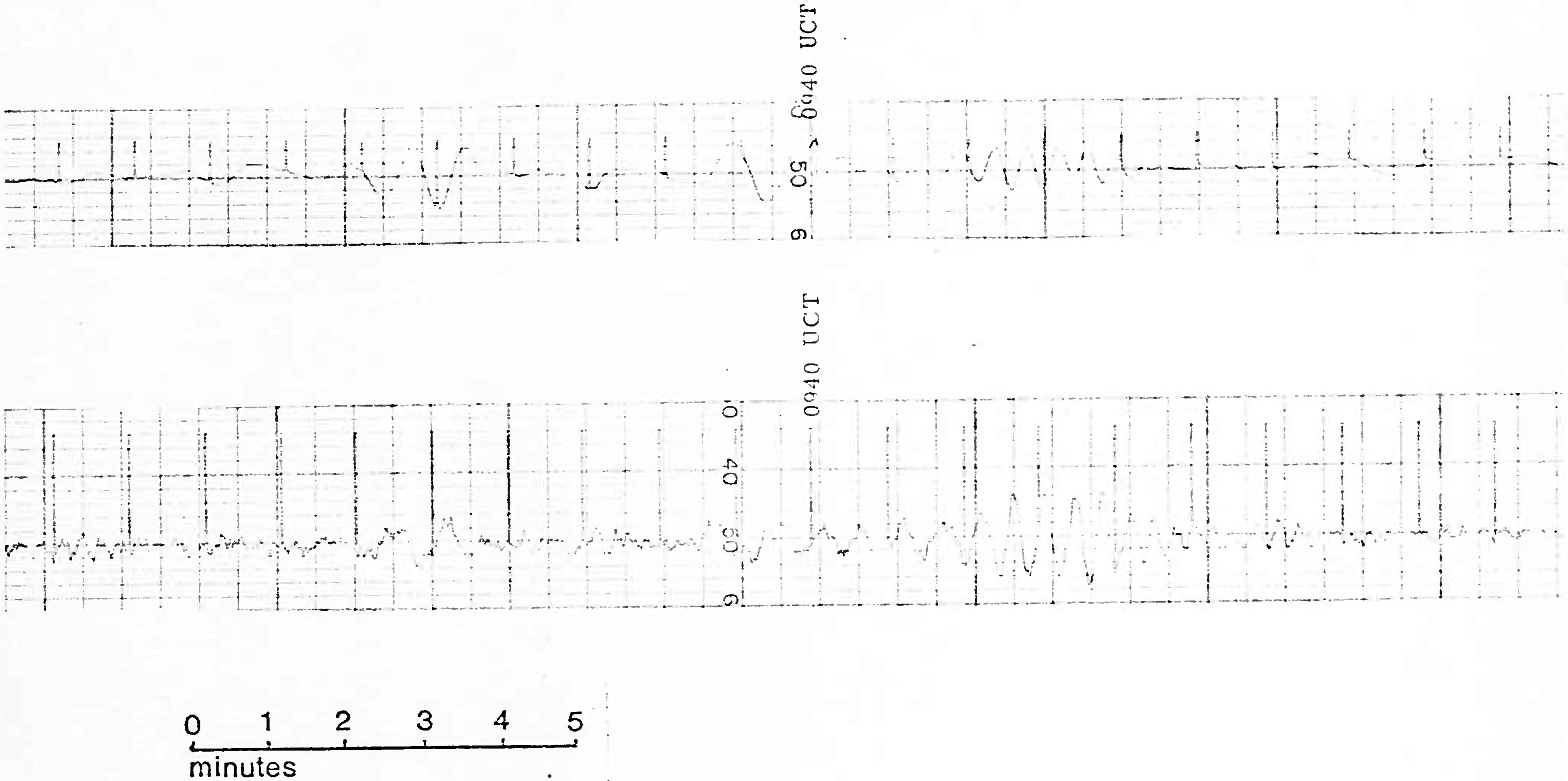
Vertical seismogram Station WPM T_o=30 sec. Geotech AS-650 amplifier
Gain 88,000 without filter galvanometer

Figure 7



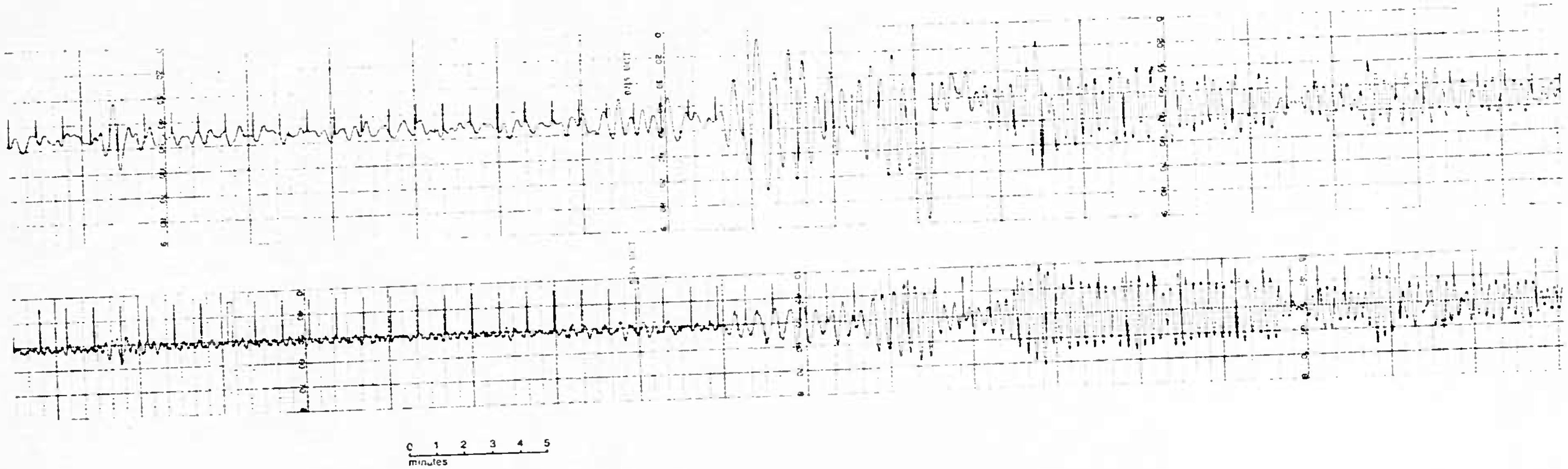
Comparison of phototube amplifier (tcp) and AS-650 amplifier (bottom) signals from HGLP vertical seismometer. Event from Kurile Islands, 46.2 N, 153.2 E, depth 42 km, on July 30, 1974 at 223944.5 UCT, Mb=5.0, Ms=4.7

Figure 8



Comparison of phototube amplifier (top) and AS-650 amplifier (bottom) signals from HGLP vertical seismometer. Event from Kenai Peninsula, Alaska, 60.5 N, 150 W, depth 44 km, on July 31, 1974 at 092051.6 UCT, Mb=4.3

Figure 9

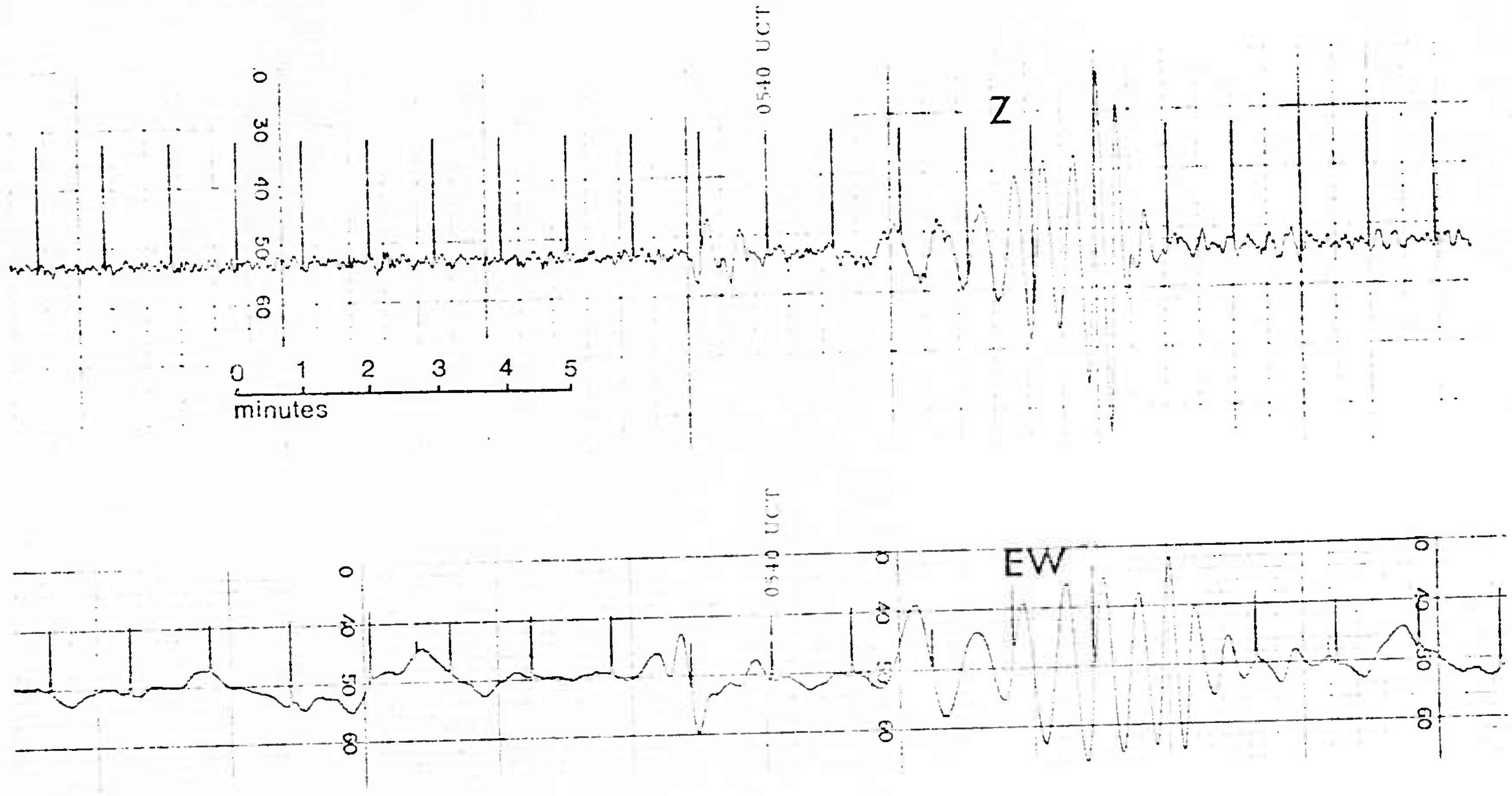


Comparison of phototube amplifier (top) and AS-650 amplifier (bottom) signals from HGLP vertical seismometer. Event from Solomon Islands, 8.6 S, 157.6 E, depth 30 km, on August 1, 1974 at 012630.1 UCT, Mb=4.8, Ms=5.1

Figure 10

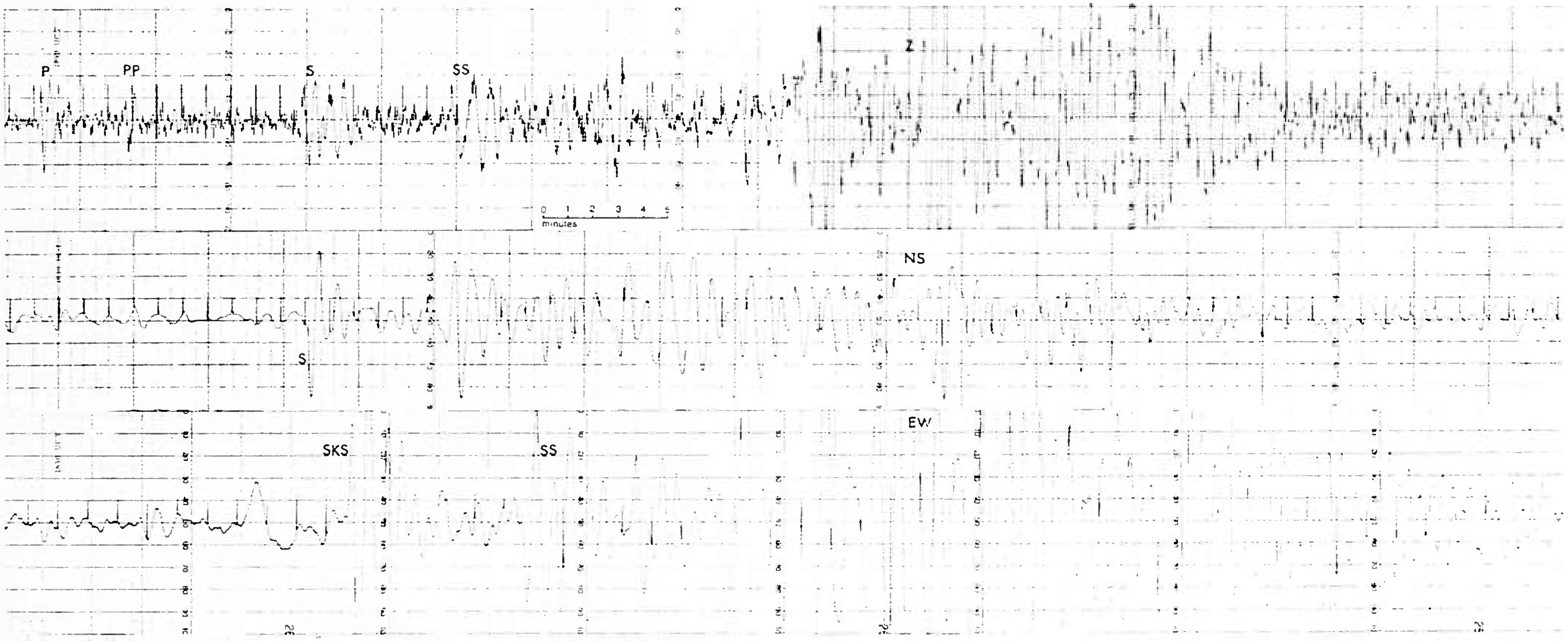
Vertical, North-South, and East-West HGLP records for an event in the Greenland Sea, 73.4 N, 6.5 E, normal depth on August 8, 1974 at 232442.4 UCT, Mb=4.2, Ms=4.5. For HGLP East-West records, advance rate is 15 mm per minute rather than 12.5.

Figure 11



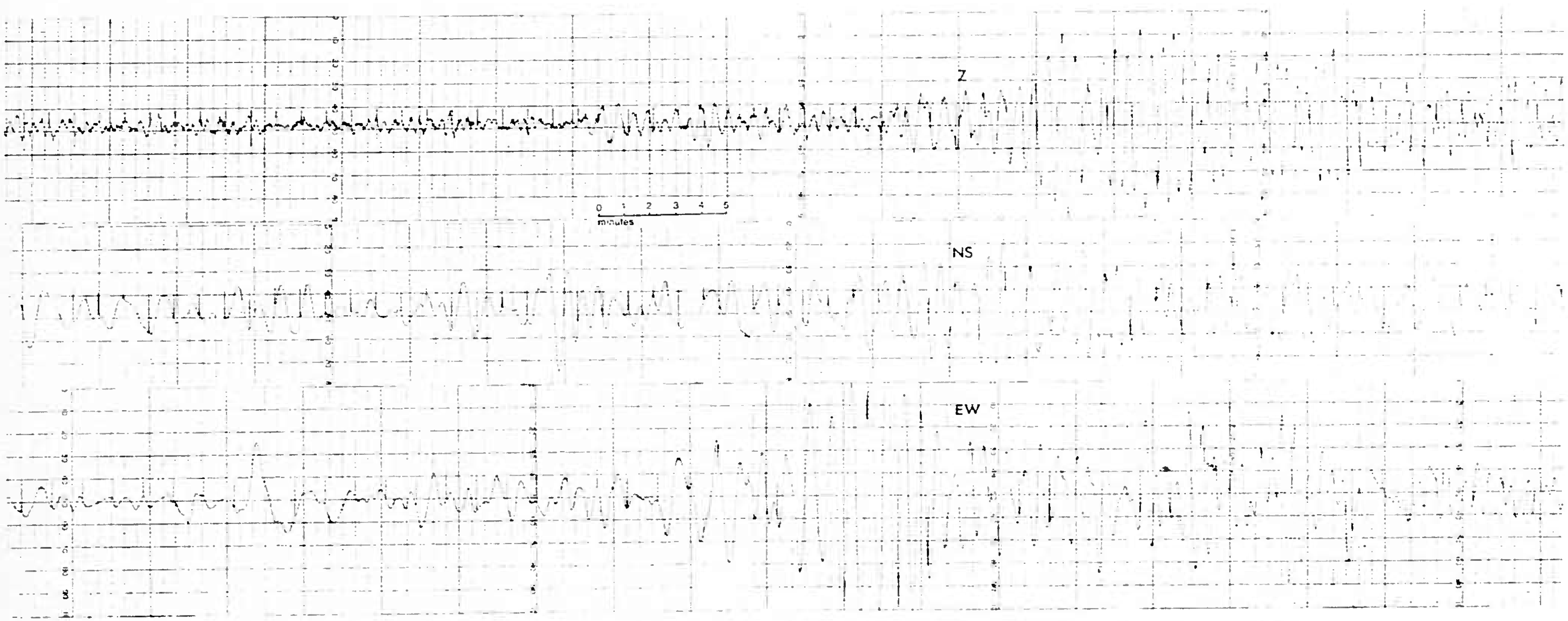
Vertical and East-West HGLP records for an event off the coast of Northern California, 41.9 N, 126.7 W, normal depth on July 26, 1974 at 052815.9 UCT, Mb=4.4. For HGLP East-West record, advance rate is 15 mm per minute instead of 12.5.

Figure 12



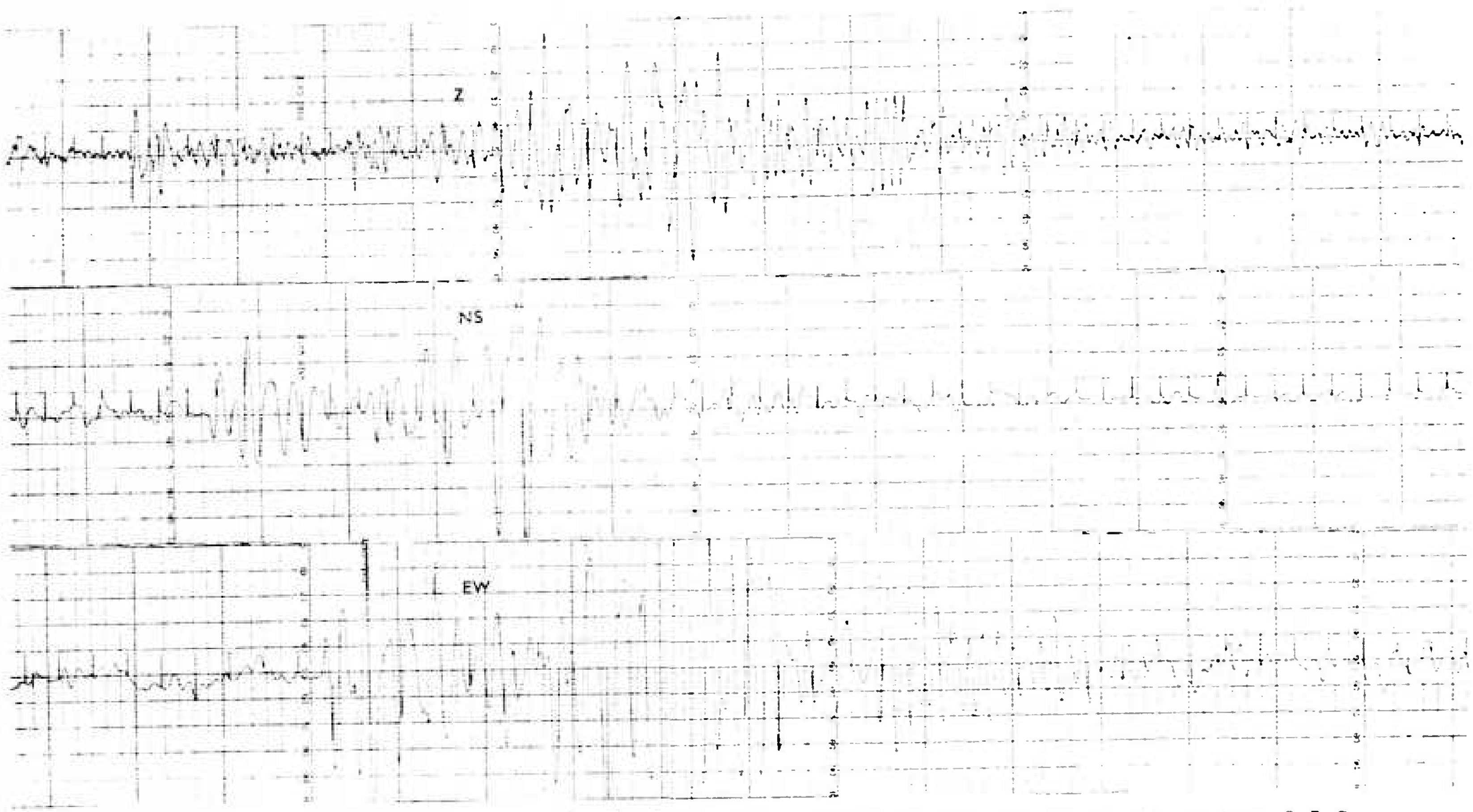
Vertical, North-South and East-West HGLP records for an event on August 3, 1974, location unknown. Statistics on this event have not yet been reported. For HGLP East-West records, advance rate is 15 mm per minute instead of 12.5.

Figure 13



Vertical (high and low gain), North-South, and East-West HGLP records. Event at Tadyhik-Sinkiang Border Region, 39.4 N, 73.9 E, normal depth on August 11, 1974 at 070208.5 UCT, Mb=5.2, Ms=5.4. For HGLP East-West records, advance rate is 15 mm per minute instead of 12.5.

Figure 14



Vertical, North-South, East-West records for HGLP, WPM. Event at Peru-Brazil Border Region, 8.5 S, 74.3 W, depth 159 km, on August 9, 1974 at 045330.7 UCT, Mb=5.6. For HGLP East-West records, advance rate is 15 mm per minute instead of 12.5.